APPENDIX G
NOISE

AIRCRAFT NOISE ANALYSIS

Noise is generally described as unwanted sound. Unwanted sound can be based on objective effects (hearing loss, damage to structures, etc.) or subjective judgments (community annoyance). Noise analysis thus requires a combination of physical measurement of sound, physical and physiological effects, plus psycho- and socioacoustic effects.

Section 1 of this Appendix describes how sound is measured, and summarizes noise impact in terms of community acceptability and land use compatibility. Section 2 gives detailed descriptions of the effects of noise which lead to the impact guidelines presented in Section 1. Section 3 provides a description of the specific methods used to predict aircraft noise.

1.0 NOISE DESCRIPTORS AND IMPACT

The aircraft noise assessed in this document is the continuous sound generated by the aircraft's engines and also by air flowing over the aircraft itself. Section 1.1 describes the quantities which are used to describe sound. Section 1.2 describes the specific noise metrics used for noise impact analysis. Section 1.3 describes how environmental impact and land use compatibility are judged in terms of these quantities.

1.1 QUANTIFYING SOUND

Measurement and perception of sound involves two basic physical characteristics: amplitude and frequency. Amplitude is a measure of the strength of the sound and is directly measured in terms of the pressure of a sound wave. Because sound pressure varies in time, various types of pressure averages are usually used. Frequency, commonly perceived as pitch, is the number of times per second the sound causes air molecules to oscillate. Frequency is measured in units of cycles per second, or Hertz (Hz).

Amplitude. The loudest sounds the human ear can comfortably hear have acoustic energy one trillion times the acoustic energy of sounds the ear can barely detect. Because of this vast range, attempts to represent sound amplitude by pressure are generally unwieldy. Sound is therefore usually represented on a logarithmic scale with a unit called the decibel (dB). Sound on the decibel scale is referred to as a sound level. The threshold of human hearing is approximately 0 dB, and the threshold of discomfort or pain is around 120 dB.

Because of the logarithmic nature of the decibel scale, sounds levels do not add and subtract directly and are somewhat cumbersome to handle mathematically. However, some simple rules of thumb are useful in dealing with sound levels. First, if a sound's intensity is doubled, the sound level increases by 3 dB, regardless of the initial sound level. Thus, for example:

60 dB + 60 dB = 63 dB, and

80 dB + 80 dB = 83 dB.

The total sound level produced by two sounds of different levels is usually only slightly more than the higher of the two. For example:

60.0 dB + 70.0 dB = 70.4 dB.

Because the addition of sound levels behaves differently than that of ordinary numbers, such addition is often referred to as "decibel addition" or "energy addition." The latter term arises from the fact that combination of decibel values consists of first converting each decibel value to its corresponding acoustic energy, then adding the energies using the normal rules of addition, and finally converting the total energy back to its decibel equivalent.

The difference in dB between two sounds represents the ratio of the amplitudes of those two sounds. Because human senses tend to be proportional (i.e., detect whether one sound is twice as big as another) rather than absolute (i.e., detect whether one sound is a given number of pressure units bigger than another), the decibel scale correlates well with human response.

Under laboratory conditions, differences in sound level of 1 dB can be detected by the human ear. In the community, the smallest change in average noise level that can be detected is about 3 dB. A change in sound level of about 10 dB is usually perceived by the average person as a doubling (or halving) of the sound's loudness, and this relation holds true for loud sounds and for quieter sounds. A decrease in sound level of 10 dB actually represents a 90 percent decrease in sound *intensity* but only a 50 percent decrease in perceived *loudness* because of the nonlinear response of the human ear (similar to most human senses).

Frequency. The normal human ear can hear frequencies from about 20 Hz to about 20,000 Hz. It is most sensitive to sounds in the 1,000 to 4,000 Hz range. When measuring community response to noise, it is common to adjust the frequency content of the measured sound to correspond to the frequency sensitivity of the human ear. This adjustment is called A-weighting (American National Standards Institute [ANSI] 1988). Sound levels that have been so adjusted are referred to as A-weighted sound levels. The amplitude of A-weighted sound levels is measured in dB. It is common for some noise analysts to denote the unit of A-weighted sounds by dBA or dB(A). As long as the use of A-weighting is understood, there is no difference between dB, dBA or dB(A). It is only important that the use of A-weighting be made clear. In this study, sound levels are reported in dB and are A-weighted unless otherwise specified.

Time Averaging. Sound pressure of a continuous sound varies greatly with time, so it is customary to deal with sound levels that represent averages over time. Levels presented as instantaneous (i.e., as might be read from the dial of a sound level meter), are based on averages of sound energy over either 1/8 second (fast) or one second (slow). The formal definitions of fast and slow levels are somewhat complex, with details that are important to the makers and users of instrumentation. They may, however, be thought of as levels corresponding to the root-mean-square sound pressure measured over the 1/8-second or 1-second periods. The most common uses of the fast or slow sound level in environmental analysis is in the discussion of the maximum sound level that occurs from the action, and in discussions of typical sound levels. Figure G-1 is a chart of A-weighted sound levels of typical sounds. Some (air conditioner, vacuum cleaner) are continuous sounds whose levels are constant for some time. Some (automobile, heavy truck) are the maximum sound during a vehicle passby. Some (urban daytime, urban nighttime) are averages over some extended period. A variety of noise metrics have been developed to describe noise over different time periods. These are described in Section 1.2.

1.2 NOISE METRICS

1.2.1 Maximum Sound Level

The highest A-weighted sound level measured during a single event in which the sound level changes value as time goes on (e.g., an aircraft overflight) is called the maximum A-weighted sound level or maximum sound level, for short. It is usually abbreviated by ALM, L_{max} or L_{Amax}. The maximum sound level is important in judging the interference caused by a noise event with conversation, TV or radio listening, sleep, or other common activities.

1.2.2 Peak Sound Level

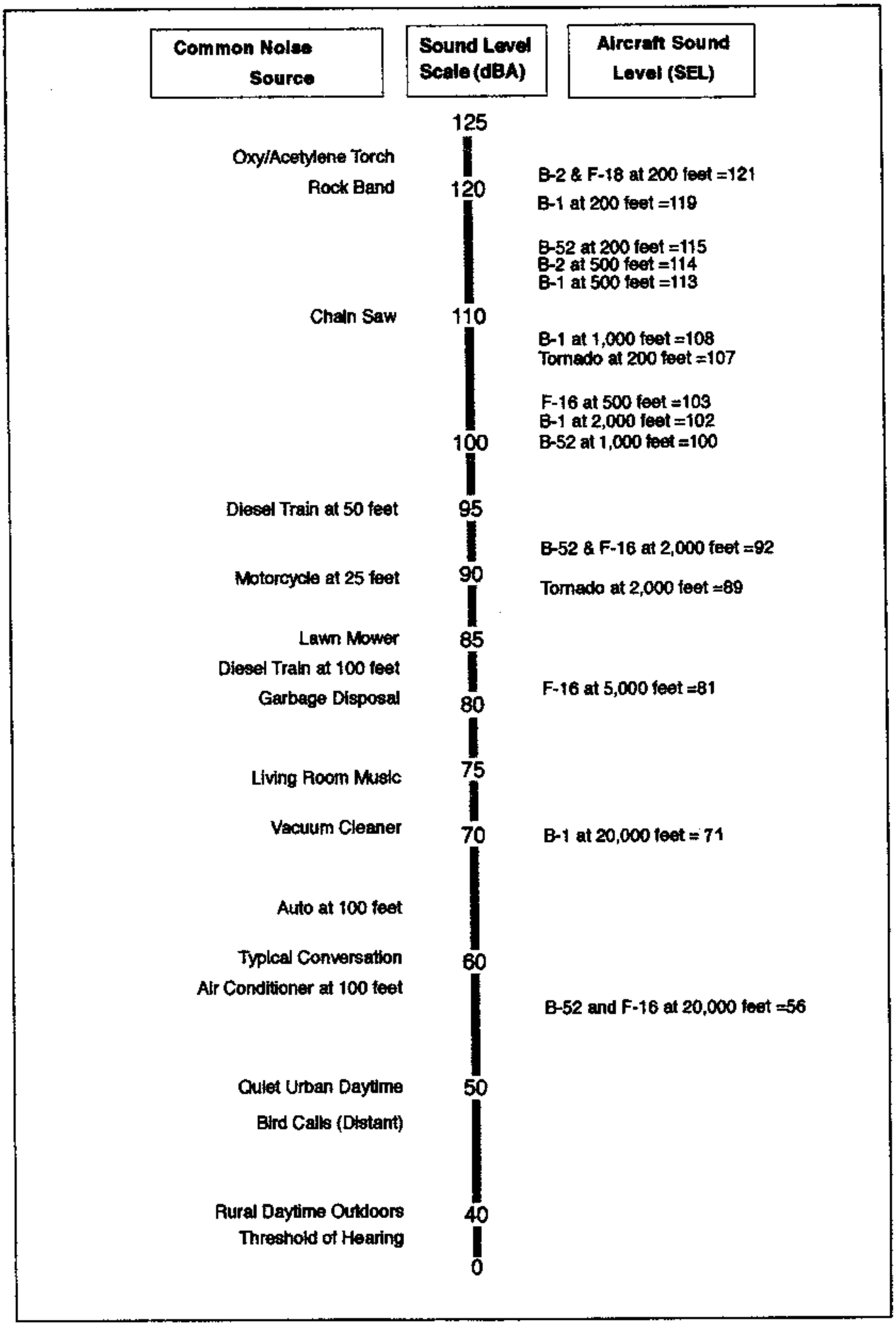
For impulsive sounds, the true instantaneous sound pressure is of interest. For sonic booms, this is the peak pressure of the shock wave. This pressure is usually presented in physical units of pounds per square foot. Sometimes it is represented on the decibel scale, with symbol L_{pk}. Peak sound levels do not use A weighting.

1.2.3 Sound Exposure Level

Individual time-varying noise events have two main characteristics—a sound level which changes throughout the event and a period of time during which the event is heard. Although the maximum sound level, described above, provides some measure of the intrusiveness of the event, it alone does not completely describe the total event. The period of time during which the sound is heard is also significant. The Sound Exposure Level (abbreviated SEL or L_{AE} for A-weighted sounds) combines both of these characteristics into a single metric.

Sound exposure level is a composite metric which represents both the intensity of a sound and its duration. Mathematically, the mean square sound pressure is computed over the duration of the event, then multiplied by the duration in seconds, and the resultant product is turned into a sound level. It does not directly represent the sound level heard at any given time, but rather provides a measure of the net impact of the entire acoustic event. It has been well established in the scientific community that Sound Exposure Level measures this impact much more reliably than just the maximum sound level.

Because the sound exposure level and the maximum sound level are both used to describe single events, there is sometimes confusion between the two, so the specific metric used should be clearly stated.



Typical A-Weighted Sound Levels of Common Sounds **Figure G-1**

1.2.4 Equivalent Sound Level

For longer periods of time, total sound is represented by the equivalent continuous sound pressure level (L_{eq}). L_{eq} is the average sound level over some time period (often an hour or a day, but any explicit time span can be specified), with the averaging being done on the same energy basis as used for SEL. SEL and L_{eq} are closely related, differing by (a) whether they are applied over a specific time period or over an event, and (b) whether the duration of the event is included or divided out.

Just as SEL has proven to be a good measure of the noise impact of a single event, L_{eq} has been established to be a good measure of the impact of a series of events during a given time period. Also, while L_{eq} is defined as an average, it is effectively a sum over that time period and is thus a measure of the cumulative impact of noise.

1.2.5 Day-Night Average Sound Level

Noise tends to be more intrusive at night than during the day. This effect is accounted for by applying a 10-dB penalty to events that occur after 10 PM and before 7 AM. If L_{eq} is computed over a 24-hour period with this nighttime penalty applied, the result is the day-night average sound level (DNL or L_{dn}). DNL is the community noise metric recommended by the U.S. Environmental Protection Agency (U.S. Environmental Protection Agency [USEPA] 1972) and has been adopted by most federal agencies (Federal Interagency Committee on Noise [FICON] 1992). It has been well established that DNL correlates well with community response to noise (Schultz 1978; Finegold *et al*. 1994). This correlation is presented in Section 1.3.

While DNL carries the nomenclature “average,” it incorporates all of the noise at a given location. For this reason, DNL is often referred to as a “cumulative” metric. It accounts for the total, or cumulative, noise impact.

1.2.6 Onset-Adjusted Monthly Day-Night Average Sound Level

Aircraft operations in military airspaces generate a noise environment somewhat different from other community noise environments. Overflights are sporadic, occurring at random times and varying from day to day and week to week. This situation differs from most community noise environments, in which noise tends to be continuous or patterned. Individual military overflight events also differ from typical community noise events: noise from a low-altitude, high-airspeed flyover can have a rather sudden onset.

To represent these differences, the conventional Day-Night Average Sound Level metric is adjusted to account for the “surprise” effect of the sudden onset of aircraft noise events on humans. For aircraft exhibiting a rate of increase in sound level (called onset rate) of 15 to 150 dB per second, an adjustment or penalty ranging from 0 to 11 dB is added to the normal Sound Exposure Level. Onset rates above 150 dB per second require an 11 dB penalty, while onset rates below 15 dB per second require no adjustment. The Day-Night Average Sound Level is then determined in the same manner as for conventional aircraft noise events and is designated as Onset-Rate Adjusted Day-Night Average Sound Level (abbreviated L_{dnmr}). Because of the irregular occurrences of aircraft operations, the number of average daily operations is determined by using the calendar month with the highest number of operations. The monthly average is denoted L_{dnmr}.

1.3 NOISE IMPACT

1.3.1 Community Reaction

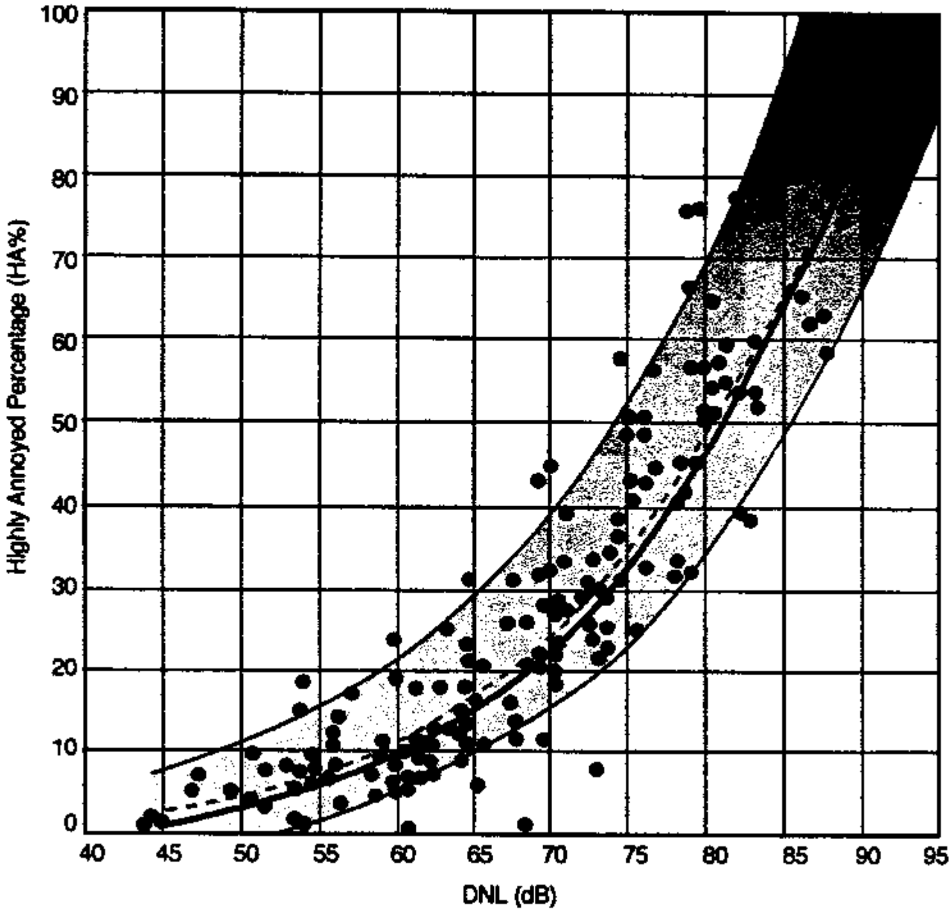
Studies of community annoyance to numerous types of environmental noise show that DNL correlates well with impact. Schultz (1978) showed a consistent relationship between DNL and annoyance. Figure G-2 shows Shultz's original curve fit. This result shows that there is a remarkable consistency in results of attitudinal surveys which relate the percentages of groups of people who express various degrees of annoyance when exposed to different Day-Night Average Sound Levels.

A more recent study has reaffirmed this relationship (Fidell *et al.* 1991). Figure G-3 (FICON 1992) shows an updated form of the curve fit (Finegold *et al*. 1994) in comparison with the original. The updated fit, which does not differ substantially from the original, is the current preferred form. In general, correlation coefficients of 0.85 to 0.95 are found between the percentages of groups of people highly annoyed and the level of average noise exposure. The correlation coefficients for the annoyance of individuals are relatively low, however, on the order of 0.5 or less. This is not surprising, considering the varying personal factors which influence the manner in which individuals react to noise. Nevertheless, findings substantiate that community annoyance to aircraft noise is represented quite reliably using Day-Night Average Sound Level.

As noted earlier for Sound Exposure Level, Day-Night Average Sound Level does not represent the sound level heard at any particular time, but rather represents the total sound exposure. It accounts for the sound level of individual noise events, the duration of those events, and the number of events. Its use is endorsed by the scientific community (ANSI 1988, ANSI 1980, FICON 1992, FICUN 1980, USEPA 1972).

While DNL is the best metric for quantitatively assessing cumulative noise impact, it does not lend itself to intuitive interpretation by non-experts. Accordingly, it is common for environmental noise analyses to include other metrics for illustrative purposes. A general indication of the noise environment can be presented by noting the maximum sound levels which can occur and the number of times per day noise events will be loud enough to be heard. Use of other metrics as supplements to DNL has been endorsed by federal agencies (FICON 1992).

There are several points of interest in the noise-annoyance relation. The first is DNL of 65 dB. This is a level most commonly used for noise planning purposes, and represents a compromise between community impact and the need for activities like aviation which do cause noise. Areas exposed to DNL above 65 dB are generally not considered suitable for residential use. The second is DNL of 55 dB, which was identified by EPA as a level below which there is effectively no adverse impact (USEPA 1972). The third is DNL of 75 dB. This is the lowest level at which adverse health effects could be credible (USEPA 1972). The very high annoyance levels make such areas unsuitable for residential land use.



Source: Schultz, 1978.

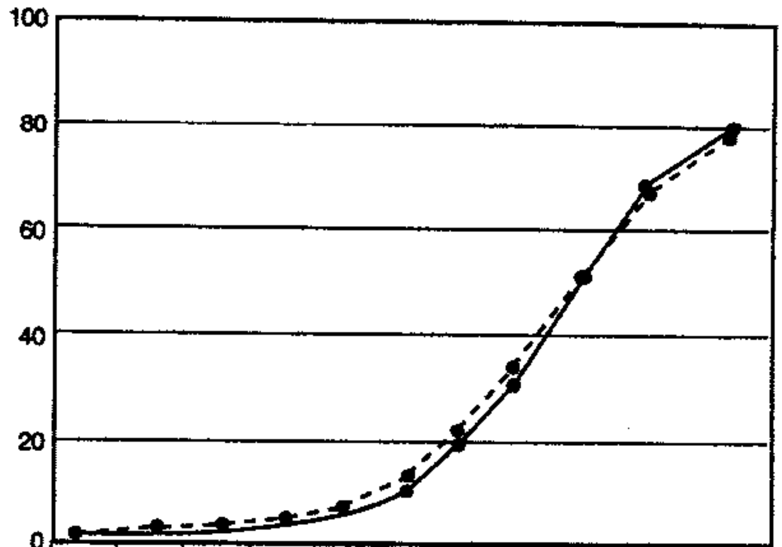
LEGEND

- - - - $\%HA = 0.8553\ L_{dn} - 0.0401\ L_{dn}^2 + 0.00047\ L_{dn}^3$

——— All 161 Data Points Given Equal Weight

All Surveys Given Equal Weight

Community Surveys of Noise Annoyance **Figure G-2**



Day-Night Average Sound Level in dB		40	45	50	55	60	65	70	75	80	85	90
Calculated % HA Points	FINEGOLD	0.41	0.83	1.66	3.31	6.48	12.3	22.1	36.5	53.7	70.2	82.6
	SCHULTZ	0.58	1.11	2.12	4.03	7.52	13.6	23.3	37.1	53.3	68.8	81

LEGEND

Finegold DATA 400 POINTS (Finegold et al. 1992)
%HA = 100/[1 + EXP (11.13 - 0.141 LDN)]

SCHULTZ DATA 161 POINTS
%HA = 100/[1 + EXP (10.43 - 0.132 LDN)]

HA = Highly Annoyed

Response of Communities to Noise; Comparison of Original (Schultz 1978) and Current (Finegold *et al.* 1994) Curve Fits

Figure G-3

1.3.2. Land Use Compatibility

As noted above, the inherent variability between individuals makes it impossible to predict accurately how any individual will react to a given noise event. Nevertheless, when a community is considered as a whole, its overall reaction to noise can be represented with a high degree of confidence. As described above, the best noise exposure metric for this correlation is the Day-Night Average Sound Level or Onset-Rate Adjusted Day-Night Average Sound Level for military overflights.

In June 1980, an ad hoc Federal Interagency Committee on Urban Noise published guidelines (FICUN 1980) relating Day-Night Average Sound Levels to compatible land uses. This committee was composed of representatives from the United States Departments of Defense, Transportation, and Housing and Urban Development; the Environmental Protection Agency; and the Veterans Administration. Since the issuance of these guidelines, federal agencies have generally adopted these guidelines for their noise analyses.

Following the lead of the committee, the Department of Defense and the Federal Aviation Administration (FAA) adopted the concept of land-use compatibility as the accepted measure of aircraft noise effect. The FAA included the committee's guidelines in the Federal Aviation Regulations. These regulations are reprinted in Table G-1, along with the explanatory notes included in the regulation. Although these guidelines are not mandatory (note the footnote “*” in the table), they provide the best means for determining noise impact in airport communities. In general, residential land uses normally are not compatible with outdoor Day-Night Average Sound Levels (DNL values) above 65 dB, and the extent of land areas and populations exposed to DNL of 65 dB and higher provides the best means for assessing the noise impacts of alternative aircraft actions.

2.0 NOISE EFFECTS

The discussion in section 1.3 presents the global effect of noise on communities. The following sections describe particular noise effects.

2.1 HEARING LOSS

Noise-induced hearing loss is probably the best defined of the potential effects of human exposure to excessive noise. Federal work place standards for protection from hearing loss allow a time-average level of 90 dB over an 8-hour work period, or 85 dB averaged over a 16-hour period. Even the most protective criterion (no measurable hearing loss for the most sensitive portion of the population at the ear's most sensitive frequency, 4,000 Hz, after a 40-year exposure) suggests a time-average sound level of 70 dB over a 24-hour period (USEPA 1972).

Table G-1. Land-Use Compatibility With Yearly Day-Night Average Sound Levels

Land Use	Yearly Day-Night Average Sound Level (DNL) in Decibels					
	Below 65	65–70	70–75	75–80	80–85	Over 85
Residential						
Residential, other than mobile homes and transient lodgings	Y	N(1)	N(1)	N	N	N
Mobile home parks	Y	N	N	N	N	N
Transient lodgings	Y	N(1)	N(1)	N(1)	N	N
Public Use						
Schools	Y	N(1)	N(1)	N	N	N
Hospitals and nursing homes	Y	25	30	N	N	N
Churches, auditoria, and concert halls	Y	25	30	N	N	N
Government services	Y	Y	25	30	N	N
Transportation	Y	Y	Y(2)	Y(3)	Y(4)	Y(4)
Parking	Y	Y	Y(2)	Y(3)	Y(4)	N
Commercial Use						
Offices, business and professional	Y	Y	25	30	N	N
Wholesale and retail—building materials, hardware, and farm equipment	Y	Y	Y(2)	Y(3)	Y(4)	N
Retail trade—general	Y	Y	25	30	N	N
Utilities	Y	Y	Y(2)	Y(3)	Y(4)	N
Communication	Y	Y	25	30	N	N
Manufacturing and Production						
Manufacturing, general	Y	Y	Y(2)	Y(3)	Y(4)	N
Photographic and optical	Y	Y	25	30	N	N
Agriculture (except livestock) and forestry	Y	Y(6)	Y(7)	Y(8)	Y(8)	Y(8)
Livestock farming and breeding	Y	Y(6)	Y(7)	N	N	N
Mining and fishing, resource production and extraction	Y	Y	Y	Y	Y	Y
Recreational						
Outdoor sports arenas and spectator sports	Y	Y(5)	Y(5)	N	N	N
Outdoor music shells, amphitheaters	Y	N	N	N	N	N
Nature exhibits and zoos	Y	Y	N	N	N	N
Amusements, parks, resorts, and camps	Y	Y	Y	N	N	N
Golf courses, riding stables, and water recreation	Y	Y	25	30	N	N

Numbers in parentheses refer to notes.

* The designations contained in this table do not constitute a federal determination that any use of land covered by the program is acceptable or unacceptable under federal, state, or local law. The responsibility for determining the acceptable and permissible land uses and the relationship between specific properties and specific noise contours rests with the local authorities. FAA determinations under Part 150 are not intended to substitute federally determined land uses for those determined to be appropriate by local authorities in response to locally determined needs and values in achieving noise-compatible land uses.

KEY TO TABLE G-1

SLUCM = Standard Land-Use Coding Manual.
Y (YES) = Land Use and related structures compatible without restrictions.
N (No) = Land Use and related structures are not compatible and should be prohibited.
NLR = Noise Level Reduction (outdoor to indoor) to be achieved through incorporation of noise attenuation into the design and construction of the structure.
25, 30, or 35 = Land Use and related structures generally compatible; measures to achieve NLR of 25, 30, or 35 dB must be incorporated into design and construction of structures.

NOTES FOR TABLE G-1

(1) Where the community determines that residential or school uses must be allowed, measures to achieve outdoor-to-indoor Noise Level Reduction (NLR) of at least 25 dB and 30 dB should be incorporated into building codes and be considered in individual approvals. Normal residential construction can be expected to provide an NLR of 20 dB; thus the reduction requirements are often stated as 5, 10, or 15 dB over standard construction and normally assume mechanical ventilation and closed windows year-round. However, the use of NLR criteria will not eliminate outdoor noise problems.

(2) Measures to achieve NLR 25 dB must be incorporated into the design and construction of portions of these buildings where the public is received, office areas, noise-sensitive areas, or where the normal noise level is low.

(3) Measures to achieve NLR 30 dB must be incorporated into the design and construction of portions of these buildings where the public is received, office areas, noise-sensitive areas, or where the normal noise level is low.

(4) Measures to achieve NLR 35 dB must be incorporated into the design and construction of portions of these buildings where the public is received, office areas, noise-sensitive areas, or where the normal noise level is low.

(5) Land-use compatible provided special sound reinforcement systems are installed.

(6) Residential buildings require an NLR of 25.

(7) Residential buildings require an NLR of 30.

(8) Residential buildings not permitted.

2.2 NONAUDITORY HEALTH EFFECTS

Nonauditory health effects of long-term noise exposure, where noise may act as a risk factor, have not been found to occur at levels below those protective against noise-induced hearing loss, described above. Most studies attempting to clarify such health effects have found that noise exposure levels established for hearing protection will also protect against any potential nonauditory health effects, at least in work place conditions. The best scientific summary of these findings is contained in the lead paper at the National Institutes of Health Conference on Noise and Hearing Loss held on 22 to 24 January 1990 in Washington, D.C. This lead paper stated the following: "The nonauditory effects of chronic noise exposure, when noise is suspected to act as one of the risk factors in the development of hypertension, cardiovascular disease, and other nervous disorders, have never been proven to occur as chronic manifestations at levels below these criteria (an average of 75 dBA for complete protection against hearing loss for an eight-hour day). At the 1988 International Congress on Noise as a Public Health Problem, most studies attempting to clarify such health effects did not find them at levels below the criteria protective of noise-induced hearing loss, and even above these criteria, results regarding such health effects were ambiguous. Consequently, it can be concluded that establishing and enforcing exposure levels protecting against noise-induced hearing loss would not only solve the noise-induced hearing loss problem but also any potential nonauditory health effects in the work place." (von Gierke 1990; parenthetical wording added for clarification).

Although these findings were directed specifically at noise effects in the work place, they are equally applicable to aircraft noise effects in the community environment. Research studies regarding the nonauditory health effects of aircraft noise are ambiguous at best, and often contradictory. Yet, even those studies which purport to find such health effects use time-average noise levels of 75 dB and higher for their research.

For example, in an often-quoted paper, two UCLA researchers found a relation between aircraft noise levels under the approach path to Los Angeles International Airport (LAX) and increased mortality rates among the exposed residents by using an average noise exposure level greater than 75 dB for the "noise-exposed" population (Meecham and Shaw 1979). Nevertheless, three other UCLA professors analyzed those same data and found no relation between noise exposure and mortality rates (Frericks *et al.* 1980).

As a second example, two other UCLA researchers used this same population near LAX to show a higher rate of birth defects during the period of 1970 to 1972 when compared with a control group residing away from the airport (Jones and Tauscher 1978). Based on this report, a separate group at the U.S. Centers for Disease Control performed a more thorough study of populations near Atlanta's Hartsfield International Airport for 1970 to 1972 and found no relation in their study of 17 identified categories of birth defects to aircraft noise levels above 65 dB (Edmonds 1979).

A review of health effects, prepared by a Committee of the Health Council of the Netherlands (1996) reviewed currently available published information on this topic. They concluded that the threshold for possible long-term health effects was a 16-hour (0600 to 2200) L_{eq} of 70 dB. Projecting this to 24 hours and applying the 10 dB nighttime penalty used with DNL, this corresponds to DNL of about 75 dB. The study also affirmed the risk threshold for hearing loss, as discussed earlier.

In summary, there is no scientific basis for a claim that potential health effects exist for aircraft time-average sound levels below 75 dB.

2.3 ANNOYANCE

The primary effect of aircraft noise on exposed communities is one of annoyance. Noise annoyance is defined by the U.S. Environmental Protection Agency as any negative subjective reaction on the part of an individual or group (USEPA 1972). As noted in the discussion of Day-Night Average Sound Level above, community annoyance is best measured by that metric.

Because the EPA Levels Document (USEPA 1972) identified DNL of 55 dB as ". . . requisite to protect public health and welfare with an adequate margin of safety," it is commonly assumed that 55 dB should be adopted as a criterion for community noise analysis. From a noise exposure perspective, that would be an ideal selection. However, financial and technical resources are generally not available to achieve that goal. Most agencies have identified DNL of 65 dB as a criterion which protects those most impacted by noise, and which can often be achieved on a practical basis (FICON 1992). This corresponds to about 12 percent of the exposed population being highly annoyed. Although DNL of 65 dB is widely used as a benchmark for significant noise impact, and is often an acceptable compromise, it is not a statutory limit and it is appropriate to consider other thresholds in particular cases.

2.4 SPEECH INTERFERENCE

Speech interference associated with aircraft noise is a primary cause of annoyance to individuals on the ground. The disruption of routine activities such as radio or television listening, telephone use, or family conversation gives rise to frustration and irritation. The quality of speech communication is also important in classrooms, offices, and industrial settings and can cause fatigue and vocal strain in those who attempt to communicate over the noise. Research has shown that the use of the Sound Exposure Level metric will measure speech interference successfully, and that a Sound Exposure Level exceeding 65 dB will begin to interfere with speech communication.

2.5 SLEEP INTERFERENCE

Sleep interference is another source of annoyance associated with aircraft noise. This is especially true because of the intermittent nature and content of aircraft noise, which is more disturbing than continuous noise of equal energy and neutral meaning. Sleep interference may be measured in either of two ways. "Arousal" represents actual awakening from sleep, while a change in "sleep stage" represents a shift from one of four sleep stages to another stage of lighter sleep without actual awakening. In general, arousal requires a somewhat higher noise level than does a change in sleep stage.

An analysis sponsored by the U.S. Air Force summarized 21 published studies concerning the effects of noise on sleep (Pearsons *et al.* 1989). The analysis concluded that a lack of reliable in-home studies, combined with large differences among the results from the various laboratory studies, did not permit development of an acceptably accurate assessment procedure. The noise events used in the laboratory studies and in contrived in-home studies were presented at much higher rates of occurrence than would normally be experienced. None of the laboratory studies were of sufficiently long duration to determine any effects of habituation, such as that which would occur under normal community conditions. A recent extensive study of sleep interference in people's own homes (Ollerhead 1992) showed very little disturbance from aircraft noise.

There is some controversy associated with the recent studies, so a conservative approach should be taken in judging sleep interference. Based on older data, the U.S. Environmental Protection Agency identified an indoor Day-Night Average Sound Level of 45 dB as necessary to protect against sleep interference (USEPA 1972). Assuming a very conservative structural noise insulation of 20 dB for typical dwelling units, this corresponds to an outdoor Day-Night Average Sound Level of 65 dB as minimizing sleep interference.

A 1984 publication reviewed the probability of arousal or behavioral awakening in terms of Sound Exposure Level (Kryter 1984). Figure G-4, extracted from Figure 10.37 of Kryter (1984), indicates that an indoor Sound Exposure Level of 65 dB or lower should awaken less than 5 percent of those exposed. These results do not include any habituation over time by sleeping subjects. Nevertheless, this provides a reasonable guideline for assessing sleep interference and corresponds to similar guidance for speech interference, as noted above.

2.6 NOISE EFFECTS ON LIVESTOCK AND WILDLIFE

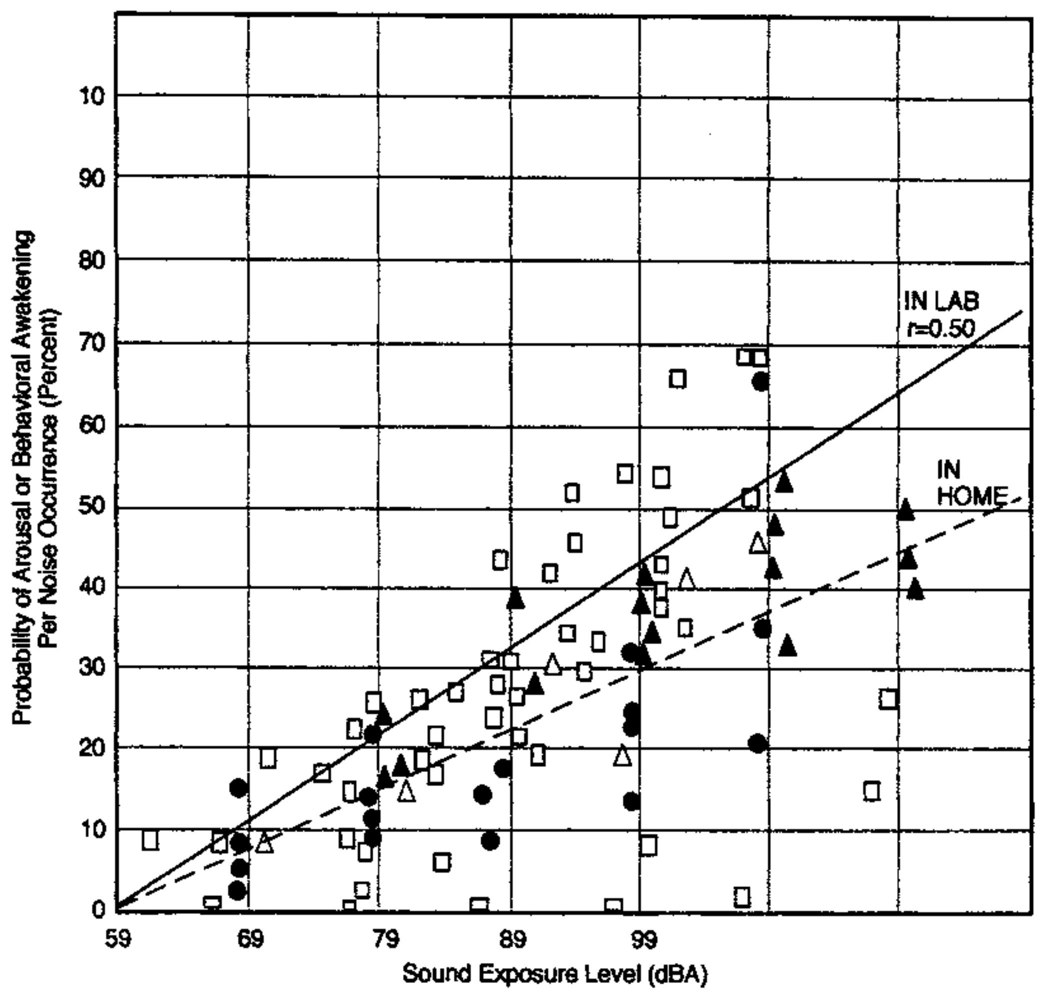
Animal responses to aircraft are influenced by many variables including aircraft size, proximity (both height above the ground and lateral distance), engine noise, color, and flight profile. The type of aircraft (e.g., fixed-wing versus rotary-winged [helicopters]) and its flight mission may also produce different levels of disturbance and animal response (Smith *et al.* 1988).

LIVESTOCK

A large bibliography of studies on the effects of aircraft noise on livestock has found a varied effect, although a large number of the studies minimize the effects of aircraft overflight on the health and well-being of these animals. The following is a summary of the literature findings by major domestic animal types found in the RBTI region. Although some studies report that the comprehensive effects on aircraft noise on domestic animals is inconclusive, a majority of the literature reviewed indicates that domestic animals exhibit minimal behavioral reactions to military overflights and seem to habituate to the disturbances over a period of time. There is no evidence from these studies that aircraft overflights affect feed intake, growth, or production rates in any way.

Cattle. A study in Sweden found that no adverse effects were observed, and behavioral reactions were considered minimal in 20 cattle and 18 sheep that were exposed to 28 sonic booms and 10 low-altitude subsonic flights over 4 days (Espmark *et al*. 1974). The authors determined there was a strong tendency for the animals to adapt to aircraft overflight disturbance, which would minimize any long-term effects.

In response to concerns about overflight effects on pregnant cattle, cattle safety and milk production, the Department of the Air Force prepared a handbook for environmental protection that summarizes the literature on the impacts of low-altitude flights on livestock (and poultry) and includes specific mention of case studies conducted in numerous airspaces across the country. Negative results have been found in a few studies, but are not reproduced in other similar studies. One study in 1983 suggested that two of ten cows in late pregnancy aborted after showing rising estrogen and falling progesterone levels correlated with 59 aircraft overflights, while the other 8 cows showed no changes in their blood concentrations and calved normally (USAF 1993). Another, in 1982, showed abortion results in 3 out of 5 pregnant cattle after exposing them to flyovers by six different aircraft



LEGEND

- □ Laboratory Studies, Variety of Noises, Lukas
- ● Steady State (In Home)
- ▲ Transient (In Home)
- △ Truck Noise, Laboratory Study, Thiesen
  Transformer, Transmission Line, Window Air Conditioner, and Distant Traffic Noise, Horonjeff

Probability of Arousal or Behavioral Awakening in Terms of Sound Exposure Level **Figure G-4**

(USAF 1993). A third study in 1983 suggests feedlot cattle could stampede and injure themselves when exposed to low level overflight (USAF 1993).

Negative findings were few, however, and the findings of little or no effect were more prevalent. A study in 1978 by Rowe and Smithies examined the causes of 1,763 abortions in Wisconsin dairy cattle over a 1-year time period and none were associated with aircraft disturbances (USAF 1993). In 1987, Anderson contacted 7 livestock operators for production data and no effects of low altitude and supersonic flights were noted. Three out of 43 cattle previously exposed to low altitude flights showed a startle response to an F/A-18 aircraft flying overhead at 500 feet AGL and 400 knots by running less than 10 meters. They resumed normal activity within 1 minute (USAF 1993). A study (Beyer 1983) found that helicopters caused more of a reaction than other low aircraft overflights and even the helicopters at 30 to 60 feet overhead did not affect milk production and pregnancies of 44 cows and heifers in a 1964 study (USAF 1993). Additionally, the 1983 Beyer study showed that 5 pregnant dairy cows in a pasture did not even run, nor disturb their pregnancies, after being overflown by 79 low-altitude helicopter flights and 4 low-altitude, subsonic jet aircraft flights (USAF 1993). A 1956 study found that the reactions of dairy and beef cattle to noise from low-altitude, subsonic aircraft were similar to those caused by flying paper, strange persons, or other moving objects (USAF 1993). In addition, Broucek (USAF 1992) found that dairy cows react to the sound of a tractor engine (97 dB) with an increased white blood cell count (the cells that fight infection), an increased sugar reserve in the blood (a response to adrenaline or fear) and a lowered red blood cell count (cells that carry oxygen to the body) (Gladwin *et al*. 1988). Overall, the U.S. Forest Service has concluded in a report to Congress (USFS 1992) that "evidence both from field studies of wild ungulates and laboratory studies of domestic stock indicate that the risks of damage are small [from aircraft approaches of 50 to 100 meters (m)], as animals take care not to damage themselves. If animals are simply overflown by aircraft at altitudes of 50 to 100 m, there is no evidence that mothers and young are separated, that animals collide with obstructions (unless confined) or that they traverse dangerous ground at too high a rate." These varied study results suggest that although the confining of cattle could magnify animal response to aircraft overflight, there is no proven cause-and-effect link between startling cattle from aircraft overflights and abortion rates or lower milk production in cattle.

Bison. Bison do not react as strongly to surrounding disturbances, as do cattle. A study in 1972 by Frazier observed bison with high and low-altitude (100-1000 feet AGL at 450 knots) overflights with F-15 aircraft at a ground noise level of 90 dBA; the bison "appeared oblivious" to the aircraft noise and continued grazing throughout all aircraft passes (Gladwin *et al*. 1988). Aircraft overflights appear to have little, if any effect on bison.

Horses. Horses have been observed for reactions to overflights as well. Several studies were summarized showing a varied response of horses to low-altitude aircraft overflights. Observations made in 1966 and 1968 noted that the horses galloped around in response to jet flyovers (USAF 1993). Bowles (1995) cites Kruger and Erath as observing horses exhibiting intensive flight reactions, random movements, and biting/kicking behavior. However, no injuries or abortions occurred and there was evidence that the mares adapted somewhat to the flyovers over a month's time (USAF 1993). Although horses notice the overflights, it does not appear to affect their survivability or their procreation and they do seem to habituate to these disturbances.

WILDLIFE

The potential sources of impacts to wildlife from aircraft overflights are the visual effect of the approaching aircraft and the associated subsonic noise. Any visual impacts would be most likely to occur along those portions of MTRs that are below 1,000 feet AGL, the altitude accounting for most reactions to visual stimuli by wildlife (Lamp 1989, Bowles 1995).

Noise effects to wildlife are classified as primary, secondary, and tertiary effects. Primary effects are direct, physiological changes to the auditory system, (i.e., ear drum rupture, temporary and permanent hearing threshold shifts, and the masking of auditory signals). These primary effects are not expected to occur as described in the following discussion. Secondary effects include non-auditory effects such as stress and associated physiological response (i.e., increased blood pressure, use of available glucose, and blood corticosteroid levels); behavior modifications; interference with mating or reproduction; and impaired ability to obtain adequate food, cover, or water. The possibility of secondary effects occurring are more likely than primary effects and will be explored in detail as follows. Tertiary effects are the direct result of primary and secondary effects, and include population declines, habitat loss, and species extinction. Tertiary effects of aircraft overflight are difficult to pinpoint because the intricate details involved in ecosystem function include many factors not related to the overflight operations.

Behavioral experiments have demonstrated that noise at high levels is mildly aversive in and of itself, apparently because the physiological effects stimulated by noise are aversive (e.g., muscular flinch, vasoconstriction, bradycardia) (Bowles 1997). However, noise is not aversive enough to be an effective conditioning stimulus over the long term. This explains the failure of most acoustic harassment devices to deter wildlife, such as deer, from favored areas (Bowles 1997).

Literature available on aircraft overflights on wildlife specifically related to the RBTI includes fixed-wing aircraft overflight studies conducted in the early 1970s through mid-1998. In the past, literature discussing different types of aircraft were used to argue whether any aircraft overflights adversely affected wildlife. Much of this literature discussed helicopter overflight, which is not included in the RBTI action. Helicopter overflight is found to have a greater effect on wildlife because helicopters do not typically leave an area as rapidly as fixed-wing aircraft. Helicopters have a percussive effect from the beat of the rotors, and helicopters are often used to chase, dart, and capture wildlife and could cause a greater fear factor among wildlife populations that have interacted with helicopters in this way. Therefore, studies on helicopters will not be discussed.

Some caution has also been suggested when extrapolating studies using one species, for the results that might happen for another. For this reason, only studies relating to RBTI-associated species will be used to discuss impacts.

Most of the effects of noise are mild enough that they may never be detectable as changes in population size or population growth against the background of normal variation (Bowles 1995). Many other environmental variables (e.g., predators, weather, changing prey base, ground based human disturbance) may influence reproductive success and confound the ability to identify the ultimate factor in limiting productivity of a certain nest, area, or region (Smith *et al.* 1988). In contrast, the effects of other human intrusions near nests, foraging areas, dens, etc. (e.g., hiking, bird watching, timber harvesting, boating) are readily detected and substantially affect wildlife behavior and reproductive success (USFS 1992).

The following discusses the aircraft overflight effects on wildlife by species type.

Large Herbivores: The large wild herbivores under the RBTI airspaces include mule deer, elk, bighorn sheep, and pronghorn antelope. There have been many studies of aircraft noise on mammals. Some of these studies have examined the noise response of mammals under laboratory conditions (e.g., Weisenberger *et al*. 1996). Other researchers have investigated the physiological and behavioral responses of mammals in the field (Lamp 1987). Laboratory studies previously showed habituation results to continuous noise exposure. Now, both the current field and laboratory data indicate that mammals (e.g., pronghorn, bighorn sheep, elk, and mule deer) show that the effects are transient and of short duration and suggest that the animals appear to habituate to noise through repeated exposure without long-term discernible negative effects (Workman *et al*. 1992; Krausman *et al*. 1993, 1998; Weisenberger *et al*. 1996). Therefore, changes to the number and types of overflight are not expected to result in major impacts to wildlife populations.

Mule deer. Mule deer were observed for jet fighter overflight responses. None of the three jet fighter flights below 3000 feet AGL and none of the 18 jet fighter flights above 3000 feet AGL caused mule deer to run (Kroodsma 1988). Wild animals exposed to intense noise with sudden onset can panic and injure themselves or their young, however, this is usually the result of active pursuit (such as the perceived pursuit of a low flying aircraft). Animals control their movements to minimize risk. Loss rates have varied greatly in the few documented cases of injury or loss. Mammals and raptors appear to have little susceptibility to those losses, whereas the most significant losses have been observed among waterfowl. Panic responses habituate quickly and completely, usually with fewer than five exposures (Bowles 1997).

Small Mammals: Small mammals under the RBTI airspaces include the Mexican long-nosed bat, black-tailed jackrabbit, black-tailed prairie dog, desert cottontail, Ord's kangaroo rat, plains harvest mouse, southern plains woodrat, and thirteen-lined ground squirrel.

One recent three-year study by McClenaghan and Bowles (1995) focused on chronic military aircraft exposure. It was conducted in south-central Arizona characterized by creosote and mixed Sonoran Desert scrub. The sites were exposed to low-altitude flights of more than 20,000 sound events in excess of 80 dB with 115.5 dB being the highest A-weighted single event level (SEL) recorded. The control sites received noise levels at least an order of magnitude lower with an average of 51.3 dB and none were over 100 dB. The control area event rate was approximately one flight per day. Numerous kangaroo rat and pocket mouse species and the white-throated wood rat were included in the study. Populations densities, body weight, reproductive activity, recruitment by immigration and reproduction, survival rate month to month were measured. Overall, the outcome of the study suggests the effects of lifetime exposure to intermittent aircraft noise on animal demography are likely to be small and difficult to detect, if they exist at all (McClenaghan and Bowles 1995), which is consistent with what is found in laboratory species and humans (Kryter 1994).

Raptors: Birds of prey, or raptors, in the area include ferruginous hawk, bald eagle, golden eagle, great-horned owl, spotted owl, burrowing owl, peregrine falcons, prairie falcons, and aplomado falcon.

Peregrine and prairie falcons: Peregrines occupy their breeding habitat by March 1, with egg laying occurring from March 15 to May 15. During this period of egg laying and initial incubation, peregrines are most susceptible to disturbance and abandonment (USFWS 1984). A study (Ellis *et* *al*. 1991) of low-altitude overflights above prairie falcon and other similar raptors showed no permanent nest abandonment or reduction in reproductive success. Abandonment is less likely during the period from May 16 until the fledged young have dispersed from the nest area (usually by August 15).

In studies on the impacts of low-altitude jet overflights on nesting peregrine and prairie falcons, Ellis (1981) and Ellis *et al.* (1991) found that responses to extremely frequent and nearby jet aircraft were often minimal and never associated with reproductive failure. Typically, birds quickly resumed normal activities within a few seconds following an overflight. While the falcons were noticeably alarmed by the noise stimuli in this study, the negative responses were brief and not detrimental to reproductive success during the course of the study.

In 1995, a three year study was initiated for the U.S. Air Force by the Alaska Cooperative Fish and Wildlife Research Unit, University of Alaska, Fairbanks, and Alaska Biological Research to assess the effects of jet overflights on the behavior, nesting success, and productivity of nesting peregrine falcons beneath five MOAs in interior Alaska (Ritchie *et al.* 1998). An average of 34 nests per year were monitored over the three year study, with an average of 28 and 27 overflights each, respectively, through the nesting season. Daily sound exposure levels (SEL) ranged from 60 to 110.6 dBA. Overall, the average number of young per successful pair was greater at the experimental sites than at the control sites (Ritchie *et al.* 1998).

Mexican Spotted Owl. Johnson and Reynolds (1996) studied F-16 aircraft overflights directly over several Mexican spotted owls located under an existing MOA. Adult and juvenile birds were observed and found to have minimal to no reactions.

Bald Eagle. Fleischner and Weisberg (1986) have shown that bald eagles are susceptible to being startled by loud noised during the breeding season. Bald eagles (threatened) typically respond to the proximity of disturbance, such as from pedestrian traffic or aircraft within 100 meters, because of the increased visibility of the perceived threat rather than noise level (Ellis *et al*. 1991). Bald eagles' reactions to commercial jet flight, although minor (e.g., looking), were twice as likely to occur at eagle-jet distances of one half mile or less (Fleischner and Weisber, 1986). Another study by Fraser *et al*. (1985) stated that over 850 overflights of active bald eagle nests only resulted in two eagles (10 percent) that interrupted their incubation or brooding activities during these overflights. Awbrey and Bowles (1990) suggested that eagles are particularly resistant to being disturbed from their nests.

Other Raptors. There have been no studies on the responses of aplomado falcons to aircraft overflights but there have been studies on the closely related peregrine and prairie falcons and other raptors (e.g., Ellis *et al*. 1991). These studies suggest that falcons will nest within areas overflown by low-level jet aircraft. Although birds do at times flush from nests, they soon return and nest success is not affected. Peregrine falcons and other raptor species are known to nest in the immediate vicinity of airports under the flight patterns where aircraft land and take-off.

Lamp (1989) found in a study of the impacts to wildlife of aircraft overflights at Naval Air Station Fallon in northern Nevada, that nesting raptors (golden eagle, bald eagle, prairie falcon, Swainson's hawk, and goshawk) either showed no response to low-level flights (less than 3,000 feet AGL) or only showed minor reactions. Minor reactions consisted of the bird assuming an alert posture or turning its head and watching the aircraft pass overhead. Duration of raptor response to aircraft disturbances was monitored for one year and was found to average 14 seconds for low-level overflights. All raptor nests under observation successfully fledged young (Lamp 1989).

In a literature review of raptor responses to aircraft noise, Manci *et al.* (1988) found that most studies of raptors did not show a negative response to overflights. When negative responses were observed they were predominantly associated with rotary-winged aircraft or jet aircraft that were repeatedly passing within one-half mile of a nest. The USFWS indicated as part of consultations associated with a Cannon AFB action that flights at or below 2,000 feet AGL from October 1 through March 1 could result in adverse impacts to wintering bald eagles (USFWS 1998). However, Fraser *et al*. (1985) believes that raptors habituate to overflights rapidly, sometimes tolerating aircraft approaches of 65 feet or less.

Other birds: The passerines present under the RBTI airspace include black-throated sparrow, dark-eyed junco, loggerhead shrike, white-faced ibis, cactus wren, mourning dove, and vesper sparrow. Federally listed birds that could be found under the airspaces include the interior least tern and southwestern willow flycatcher. As opposed to other taxa, many researchers (Bowles 1997, Ellis *et al*. 1991, Klein 1973, Pritchett *et al*. 1978) have studies the effects of aircraft noise on birds and mammals. Some of these studies have examined the noise response of birds under laboratory conditions (e.g., Book and Bradley n.d.). Other researchers have investigated the physiological and behavioral responses of birds in the field (Ellis *et al*. 1991, Henson and Grant 1991). The primary criticism of the previous laboratory studies is that the results invariably show habituation to continuous noise exposure. Both the current field and laboratory data, however, indicate that many birds appear to habituate to noise through repeated exposure without long-term discernible negative effects.

Passerines. Passerines (i.e., perching birds or song birds) cannot be driven any great distance from a favored food by a nonspecific disturbance, such as aircraft overflight (USFS 1992). However, Manci *et al*. (1988) states that reproductive losses have been reported for small territorial passerines after exposure to low-altitude overflights.

Black Ducks. One recent study measured the heart rate of black ducks for 4 days and subjected them to simulated aircraft noise for 48 episodes per day with peak volume of 110 dB. Acute response occurred on the first day but diminished rapidly after that. This indicated the ability of black ducks to habituate to the auditory component of low altitude aircraft overflight (Harms *et al*. 1997).

Migratory Waterfowl. Migratory waterfowl have shown to have moderate responses and habituate slowly to aircraft overflight. For example, migratory waterfowl often make brief flights in response to aircraft overflights. If individuals are susceptible to damage as a result of these moderate responses, noise may continue to have an impact over long periods. For example, gulls nesting in colonies can take advantage of brief defensive flights to cannibalize one another's eggs (Burger 1981). Unfortunately, little information is available on the actual extent of such losses. Migrants and animals living in areas with high concentrations of predators are the most vulnerable.

Wading Birds. A literature synthesis by Manci *et al*. (1988) cited Black *et al*. (1984) as studying wading bird colony effects of low-altitude (less than 500 feet AGL) military training flights. It was found that reproductive activity including nest success, nestling survival, and nestling chronology, was independent of F-16 overflights, but was related to ecological factors including location and physical characteristics of the colony and climatology.

Sandhill Cranes. In a literature review by the USAF (1993), two studies were referenced that noted aircraft noise caused a cessation of intensive calling, but birds rarely left the nest, when overflown.

Fish, Reptiles, and Amphibians: Reptile and amphibians identified under the RBTI airspaces include Mojave rattlesnake, side-blotched lizard, Texas horned lizard, yellow mud turtle, Texas banded gecko, Great Plains skink, Couch's spadefoot toad, and the Great Plains toad. The effects of overflight noise on fish, reptiles, and amphibians have been poorly studied, but conclusions about their expected responses have been speculated on through the known physiology and behavior for these taxa (Gladwin *et al*. 1988). Although fish do startle in response to low flying aircraft noise and probably to the shadows of aircraft as well, they have been found to habituate to the sound and overflights. Noise is also readily and well attenuated by water surfaces, fish are not expected to be affected by noise from overflights. Reptiles and amphibians that respond to low frequencies and those that respond to ground vibration, such as toads (genus *Scaphiopus*), may be affected by noise. However, RBTI activities are unlikely to cause ground vibrations noticeable to these species.

2.7 NOISE EFFECTS ON STRUCTURES

Normally, the most sensitive components of a structure to airborne noise are the windows and, infrequently, the plastered walls and ceilings. An evaluation of the peak sound pressures impinging on the structure is normally sufficient to determine the possibility of damage. In general, at sound levels above 130 dB, there is the possibility of the excitation of structural component resonance. While certain frequencies (such as 30 Hz for window breakage) may be of more concern than other frequencies, conservatively, only sounds lasting more than one second above a sound level of 130 dB are potentially damaging to structural components.

In a 1989 study, directed specifically at low-altitude, high-speed aircraft showed that there is little probability of structural damage from such operations (Sutherland 1990). One finding in that study is that sound levels at damaging frequencies (e.g., 30 Hz for window breakage or 15 to 25 Hz for whole-house response) rarely occur below 130 dB.

Noise-induced structural vibration may also cause annoyance to dwelling occupants because of induced secondary vibrations, or "rattle," of objects within the dwelling, such as hanging pictures, dishes, plaques, and bric-a-brac. Window panes may also vibrate noticeably when exposed to high levels of noise, causing homeowners fear of breakage. In general, such noise-induced vibrations occur at sound levels above those considered normally incompatible with residential land use. Thus assessments of noise exposure levels for compatible land use should also be protective of noise-induced secondary vibrations.

2.8 NOISE EFFECTS ON TERRAIN

Members of the public often perceive that noise from low-flying aircraft can cause avalanches or landslides by disturbing fragile soil or snow structures, especially in mountainous areas, causing landslides or avalanches. There are no known instances of such effects, and it is considered improbable that such effects will result from routine, subsonic aircraft operations.

2.9 NOISE EFFECTS ON HISTORICAL AND ARCHAEOLOGICAL SITES

Because of the potential for increased fragility of structural components of historical buildings and other historical sites, aircraft noise may affect such sites more severely than newer, modern structures. Again, there are few scientific studies of such effects to provide guidance for their assessment.

One study involved the measurements of sound levels and structural vibration levels in a superbly restored plantation house, originally built in 1795, and now situated approximately 1,500 feet from the centerline at the departure end of Runway 19L at Washington Dulles International Airport (IAD). These measurements were made in connection with the proposed scheduled operation of the supersonic Concorde airplane at IAD (Wesler 1977). There was special concern for the building's windows, since roughly half of the 324 panes were original. No instances of structural damage were found. Interestingly, despite the high levels of noise during Concorde takeoffs, the induced structural vibration levels were actually less than those induced by touring groups and vacuum cleaning within the building itself.

As noted above for the noise effects of noise-induced vibrations of normal structures, assessments of noise exposure levels for normally compatible land uses should also be protective of historic and archaeological sites.

3.0 NOISE MODELING

An aircraft in subsonic flight generally emits noise from two sources: the engines and flow noise around the airframe. Noise generation mechanisms are complex, and in practical models the noise sources must be based on measured data. The Air Force has developed a series of computer models and aircraft noise data bases for this purpose. The models include NOISEMAP (Moulton 1992) for noise around airbases, ROUTEMAP (Lucas and Plotkin 1988) for noise associated with low-level training routes, and MR_NMAP (Lucas and Calamia 1996) for use in MOAs and ranges. These models use the NOISEFILE database developed by the Air Force. NOISEFILE data includes SEL and L_{max} as a function of speed and power setting for aircraft in straight flight.

Noise from an individual aircraft is a time-varying continuous sound. It is first audible as the aircraft approaches, increases to a maximum when the aircraft is near its closest point, then diminishes as it departs. The noise depends on the speed and power setting of the aircraft, and its trajectory. The models noted above divide the trajectory into segments whose noise can be computed from the data in NOISEFILE. The contributions from these segments are summed.

MR_NMAP was used to compute noise levels in the affected airspace for this EIS. The primary noise metric computed by MR_NMAP was L_{dnmr} averaged over each airspace. Supporting routines from NOISEMAP were used to calculate SEL and L_{max} for various flight altitudes and lateral offsets from a ground receiver position.

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